INTERIM MEASURES WORK PLAN
SWMU 14/46

NAVAL SUPPORT ACTIVITY MID-SOUTH
MILLINGTON, TENNESSEE

Revision: 0

Comprehensive Long-Term Environmental Action Navy
Contract Number: N62467-89-D-0318
CTO-0094

Prepared for:

Naval Facilities Engineering Command
SOUTHERN DIVISION

Department of the Navy
Southern Division
Naval Facilities Engineering Command
North Charleston, South Carolina

Prepared by:

ENSAFE

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October 12, 2004

ENSAFE

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October 13, 2004

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Subject: CTO-0146; NSA Mid-South, SWMU 14/46, Millington, Tennessee

Document Transmittal – *Interim Measures Work Plan, Naval Support Activity Mid-South, SWMU 14/46, Revision 0,* October 13, 2004

Reference: Contract N62467-89-D-0318 (CLEAN II)

Dear Sir:

This letter is provided to document submittal of the *Interim Measures Work Plan, Naval Support Activity Mid-South, SWMU 14/46, Revision 0,* October 13, 2004. The document has been distributed as shown on the attached NSA Mid-South RFI Distribution List.

If you have any questions or comments of a technical nature, please contact me at 901/372-7962. Comments or questions of a contractual nature should be directed to Debra Blagg at the same number.

Sincerely,

EnSafe Inc.

By: John Stedman, Jr.
Task Order Manager

Enclosures: As Stated

cc: Contracts File: CTO-0146 (w/out enclosure)
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The Contractor, EnSafe Inc., certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N62467-89-D-0318 are complete, accurate, and comply with all requirements of the contract.

Date:	**October 12, 2004**
Signature:	
Name:	**John Stedman, Jr.**
Title:	**Task Order Manager**

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List of Abbreviations and Acronyms

1,2-DCE	1,2-dichloroethylene
A-A	anaerobic-aerobic
AOC	area of concern
bls	below land surface
BRAC	Base Closure and Realignment
CMS	Corrective Measures Study
CO_2	carbon dioxide
DCE	dichloroethylene
DO	dissolved oxygen
DPT	direct-push technology
DRO	diesel range organics
EISOPQAM	Environmental Investigation Standard Operations Procedures and Quality Assurance Manual
gpm	gallon per minute
GRO	gasoline range organics
ID	inside diameter
IM	Interim Measures
MCL	maximum contaminant level
MNA	monitored natural attenuation
MSCHD	Memphis and Shelby County Health Department
NA	not applicable
ND	not detected
NS	not sampled
NSA	Naval Support Activity
O&M	operation and maintenance
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PCE	tetrachloroethylene
PLFA	phospholipid fatty acid
psi	pounds per square inch
PVC	polyvinyl chloride
QAPP	Quality Assurance Project Plan

RGO	remedial goal option
S	Storage Capacity
SWMU	solid waste management unit
T	Transmissivity
TCE	trichloroethylene
TDEC	Tennessee Department of Environment and Conservation
TN-EPH	Tennessee Extractable Petroleum Hydrocarbons
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
UST	underground storage tank
VC	vinyl chloride
VFA	volatile fatty acids
VOC	volatile organic compound
μg/L	micrograms per liter

1.0 INTRODUCTION

Interim Measures (IM) are a valuable corrective measure option available in the Resource Conservation and Recovery Act (RCRA). The goal of the RCRA corrective action process is to evaluate, design, and implement the most appropriate long-term remedy at the site. While long-term remedies are being designed or evaluated, there is often a need to control or mitigate existing threats to human health and the environment, and prevent or lessen the further spread of contamination. The IM process is the mechanism by which existing contamination or threats are addressed and contained while long-term remedies are being pursued.

The IM effort at any one site builds on work that has already been initiated at many other previous corrective action sites. Although they are intended to be implemented more quickly than traditional remedial measures, IMs may be short-term or long-term and are developed to complement the final, comprehensive remedy for the facility.

A Corrective Measures Study (CMS) report recommended full-scale enhanced bioremediation with monitored natural attenuation (MNA) as the final, long-term remedy that should be implemented at Solid Waste Management Unit (SWMU) 14/46, located on the Southside of Naval Support Activity (NSA) Mid-South, Millington, Tennessee (EnSafe. 2003). United States Environmental Protection Agency (USEPA) and the Tennessee Department of Environmental Control (TDEC) concurred with this recommendation in letters dated February 10, 2004, and February 18, 2004, respectively. This IM work plan outlines design, construction, and operation and maintenance (O&M) requirements for enhanced bioremediation at SWMU 14/46. It also provides implementation and submittal schedules. These IMs are designed to mitigate hazards and threats to human health and the environment from the groundwater contaminated with tetrachloroethylene (PCE) and trichloroethylene (TCE) at SWMU 14/46. MNA is being implemented as the remediation of daughter products formed from the breakdown of PCE and TCE.

This IM work plan has been organized according to the Office of Solid Waste and Emergency Response (OSWER) Directive 9902.4, *RCRA Corrective Action Interim Measures Guidance* (Final, June 1998).

- **Section 1, Introduction:** This section presents the purpose of the report.

- **Section 2, Site Description and Environmental Setting:** This section presents the history and background of SWMU 14/46 and the results of previous investigations, including the RCRA Facility Investigation (RFI) and supplemental CMS sampling.

- **Section 3, Enhanced In Situ Bioremediation:** This section summarizes the remedial objectives, technology description, and results of an enhanced in situ bioremediation pilot study performed at another NSA Mid-South site with similar characteristics of SWMU 14/46.

- **Section 4, Enhanced In Situ Bioremediation Full-Scale Design:** This section outlines the system/well design of the full-scale enhanced bioremediation system and bioaugmentation design.

- **Section 5, Permit Requirements:** The section discusses the appropriate permits that are necessary to implement this remedial technology.

- **Section 6, Effectiveness Monitoring:** This section summarizes the field procedures, laboratory information, scheduling, and reporting.

- **Section 7, Schedule and Reporting:** This section provides a time line of the events that will take place during the IM.

- **Section 8, References:** This section lists applicable references used to prepare the IM work plan.

- **Section 9, Signatory Requirement:** This section provides the applicable signatory requirements for the IM work plan.

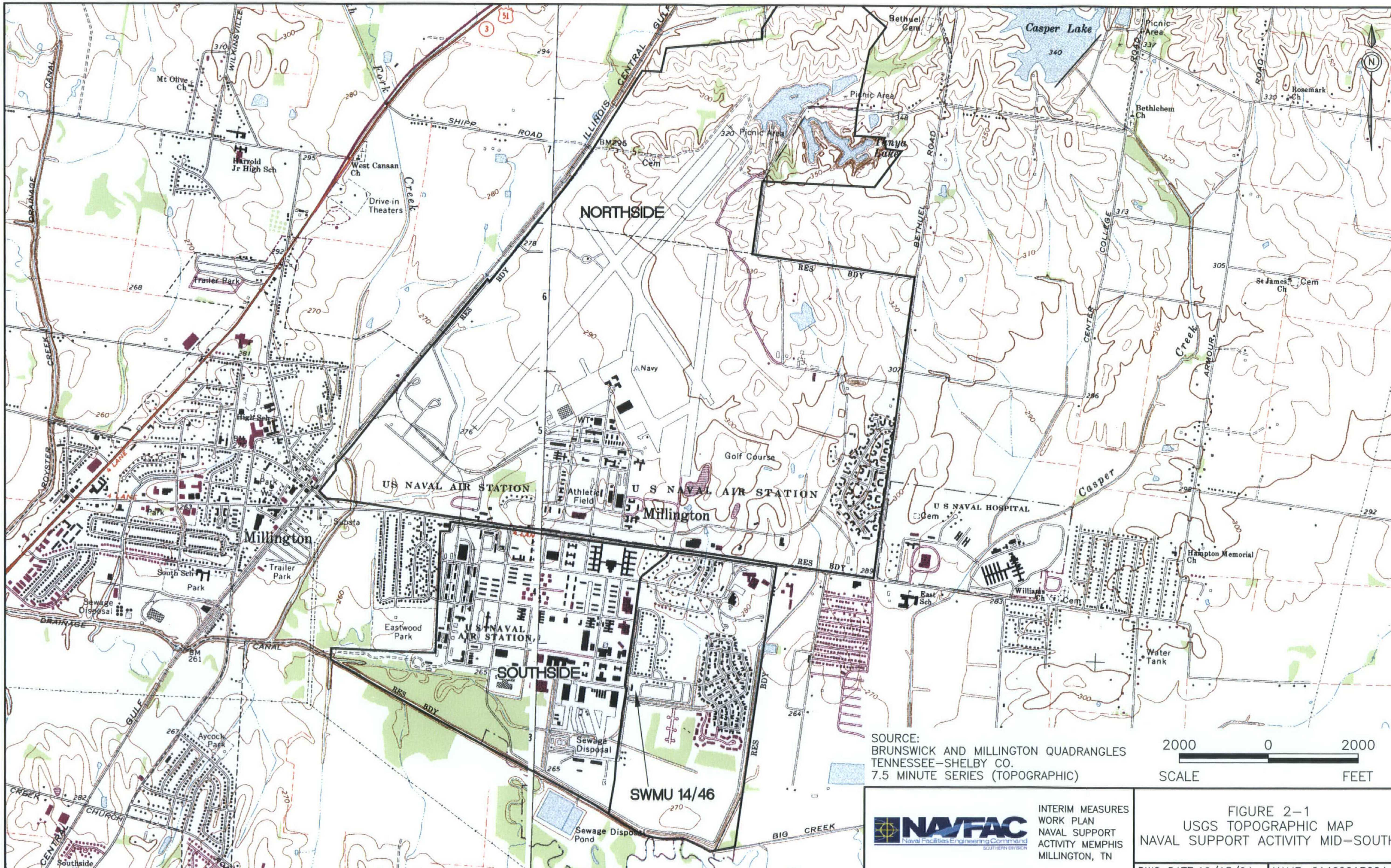
2.0 SITE DESCRIPTION AND ENVIRONMENTAL SETTING

2.1 General

SWMU 14, the former site of Building S-140, is now a flat, grass-covered area located on the southside of NSA Mid-South, east of Seventh Avenue and north of Polaris Drive. Drainage ditches run along the south and west sides of the site. The site's eastern portion features a small stand of pine trees, several sidewalks, and a large open field once used as a trailer park. Residential property is located at the far east end of this open field. Figure 2-1, a topographic map of the facility and the surrounding area, shows the NSA Mid-South Northside and Southside base boundaries that were in place before some areas of the Northside were transferred to the city of Millington as a result of the Base Closure and Realignment Act (BRAC) in January 2000, as well as the location of SWMU 14.

Building S-140, demolished in 1985, housed a paint spray booth, paint removing area, and paint wash-down area that the Navy reportedly used from 1943 to 1985 to train personnel in painting-related processes. According to building diagrams, two drainage systems were associated with painting activities at S-140: one was located in the central portion of the building, which housed the paint spray booths and water wash pits, and the other was in the northern portion near the interior wash-down area and work table.

Based on records that document the site, paint-related wastes generated by the paint spray booth and water wash pits apparently collected in two floor drains, which emptied into two 1,885-gallon sump pits. Paint waste and sludge from these sumps were most likely removed as-needed, with any overflow discharged directly to the Seventh Avenue ditch. After 1980, the flow from the paint booth and wash-down area was redirected to a paint separator and sump in the building's mechanical room, and the overflow was discharged to the sanitary sewer. The paint waste and sludge likely contained chromium, lead, various hydrocarbons, and paint solvents, including mineral spirits, toluene, and phenols.



NAVFAC Naval Facilities Engineering Command SOUTHERN DIVISION

INTERIM MEASURES WORK PLAN
NAVAL SUPPORT ACTIVITY MEMPHIS
MILLINGTON, TN

FIGURE 2–1
USGS TOPOGRAPHIC MAP
NAVAL SUPPORT ACTIVITY MID–SOUTH

DWG DATE:10/13/04 | NAME: 0146001B024

Reportedly, wastes generated by the paint wash-down area and work tables were discharged to a drain line exiting the building's east side that has never been located. In 1968, these wastes were diverted to an interceptor-separator beneath the north end of a sidewalk immediately east of the building. According to construction diagrams, this interceptor-separator was 3.5 feet long, 5 feet wide, and 4.5 feet deep. Interceptor discharge was directed to the sanitary sewer line located to the north.

A former outdoor wash basin located next to Building S-140's southside exterior wall consisted of a 36- by 40-foot concrete slab surrounded by a 6-inch berm. According to sewer modification diagrams, the basin's drain connected to a 12-inch concrete line, which ran beneath Polaris Drive and discharged directly into the southern drainage ditch across Polaris Drive. Reportedly, when the drain line was plugged in 1980, drainage was diverted to the sanitary sewer. Today, there is no evidence of the drain, but the associated outfall (a small discharge pipe) is visible in the Polaris Drive ditch.

According to the building's engineering plans, four smaller structures were also associated with the building. Building S-275, a gear locker located approximately 50 feet east of S-140, reportedly was constructed in 1944 and demolished in 1985. Building S-1602 is reported to have been a temporary structure located along the eastern edge of the site; it was removed in August 1989. Building S-351, which was located 50 feet southeast of S-140, was reportedly a 12-foot by 20-foot prefabricated metal storage building used as a paint locker prior to its demolition in 1985. Also associated with Building S-140 is SWMU 46, a former hazardous waste accumulation point located at the north end of a paved area east of the building. From 1980 until 1985, SWMU 46 was reportedly used for less-than-90-day storage of drummed hazardous waste, including waste paints and thinners. SWMUs 14 and 46 were investigated together during the RFI. Results of this SWMU 14/46 investigation are presented in the Assembly E RFI Report(EnSafe, 2000).

The site is relatively flat with no obvious direction for surface water runoff. However, it is likely that all runoff currently discharges as sheet flow to the Seventh Avenue ditch to the west and the

Polaris Drive drainage ditch to the south. These ditches, which ultimately discharge into the Big Creek Drainage Canal, are partially concrete-lined. Figure 2-2 presents a site location map.

2.2 Site Geology and Hydrogeology

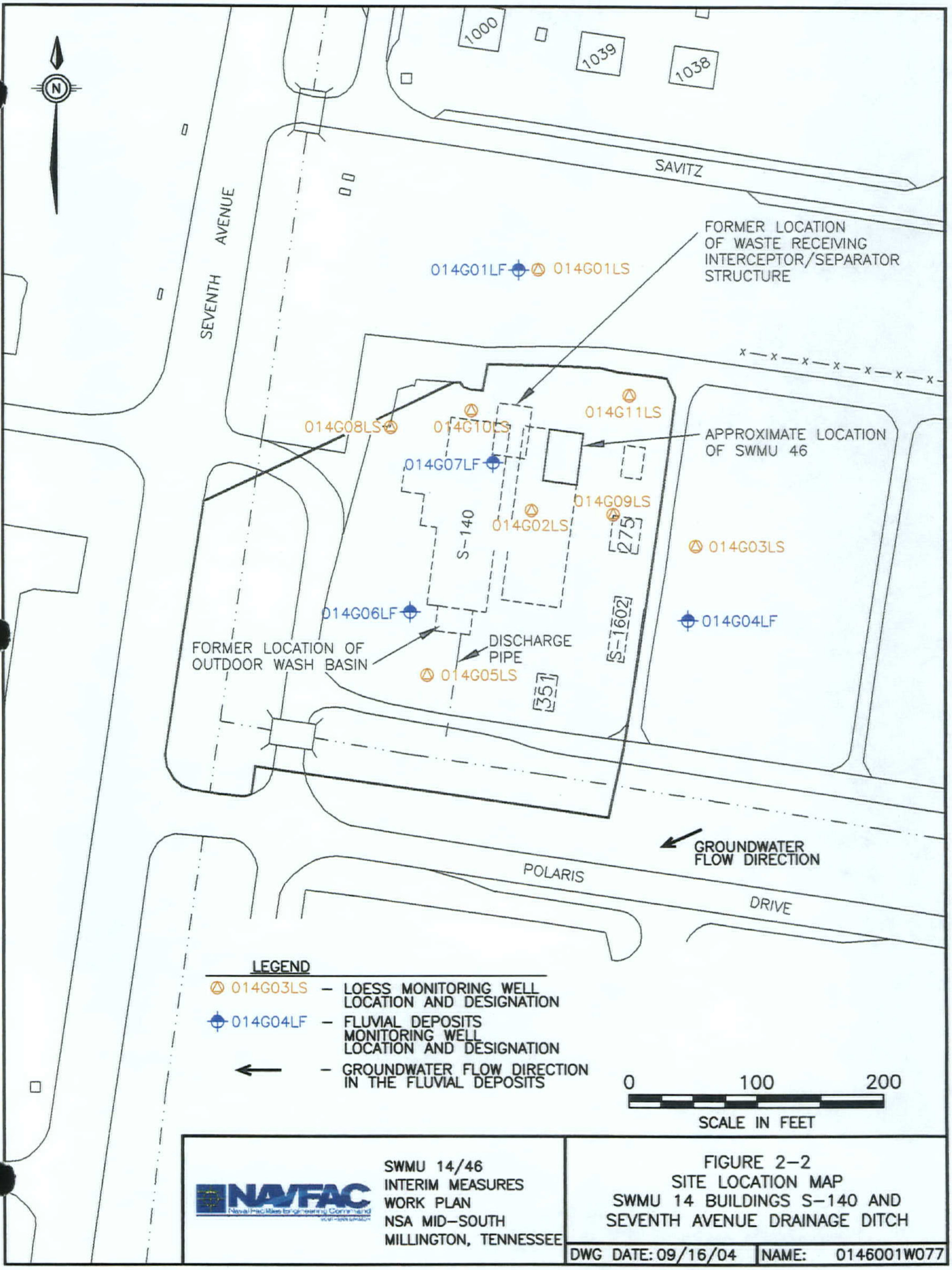
The geology of SWMU 14/46 consists of three major lithologic units, which are listed in descending order (youngest to oldest) (Carmichael, et al., 1997):

- Pleistocene-age loess
- Pleistocene- to possibly Pliocene-age fluvial deposits
- Eocene-age Cockfield and Cook Mountain Formations (upper units of the Claiborne Group), which overlie the Memphis Sand of Eocene-age and serve as the upper Claiborne confining unit for the Memphis aquifer

Two principal groundwater units have been the focus of investigations at NSA Mid-South: the alluvial-fluvial deposits aquifer, which is the most prominent surficial aquifer, and the Memphis aquifer, which is the primary drinking water source in the Memphis area. These aquifers are hydraulically separated by the Cockfield and Cook Mountain Formations, which individually range from 0 to 185 and 10 to 60 feet thick at NSA Mid-South, respectively (Carmichael, et al., 1997).

The SWMU 14/46 monitoring and background monitoring wells were screened in either the loess or fluvial deposits. The two background wells comparable to SWMU 14/46 are located 1,300 and 5,000 feet north of the Big Creek Drainage Canal.

The loess encountered in soil borings consists of clay, silty clay, clayey silt, and silt from land surface to depths ranging from 30 to 39 feet below land surface (bls). In general, the clay fraction decreases and the silt fraction increases with depth. The loess color ranges from moderate to dark yellowish-brown, brown, brownish-gray, greenish-gray, and light olive gray. Sparse to common


N
1000
1039
1038
SAVITZ
SEVENTH AVENUE
FORMER LOCATION OF WASTE RECEIVING INTERCEPTOR/SEPARATOR STRUCTURE
014G01LF
014G01LS
014G11LS
014G08LS
014G10LS
APPROXIMATE LOCATION OF SWMU 46
014G07LF
014G09LS
S-140
014G02LS
275
014G03LS
S-1602
014G06LF
014G04LF
DISCHARGE PIPE
FORMER LOCATION OF OUTDOOR WASH BASIN
014G05LS
351
GROUNDWATER FLOW DIRECTION
POLARIS
DRIVE
LEGEND
014G03LS – LOESS MONITORING WELL LOCATION AND DESIGNATION
014G04LF – FLUVIAL DEPOSITS MONITORING WELL LOCATION AND DESIGNATION
– GROUNDWATER FLOW DIRECTION IN THE FLUVIAL DEPOSITS
0
100
200
SCALE IN FEET
NAVFAC
SWMU 14/46
INTERIM MEASURES
WORK PLAN
NSA MID-SOUTH
MILLINGTON, TENNESSEE
FIGURE 2-2
SITE LOCATION MAP
SWMU 14 BUILDINGS S-140 AND
SEVENTH AVENUE DRAINAGE DITCH
DWG DATE: 09/16/04
NAME: 0146001W077

dark orangish-yellow or light olive gray mottling was observed in some soil borings, as was iron staining, iron/manganese nodules, and organic material. Hard, siliceous clayey material or concretions were present in the loess near 27 feet bls in one SWMU 14/46 soil boring.

Loess soil samples collected for geotechnical analysis consisted of one sample from SWMU 14/46 (014S01LF, 8 to 10 feet bls) and one from the United States Geological Survey (USGS) test hole north of SWMU 14/46 (TH-7, 10 to 12 feet bls). The vertical coefficient of permeability for these samples, which was calculated from falling head permeability testing, ranged from 2.83×10^{-7} centimeters per second (cm/sec) to 5.7×10^{-7} cm/sec. Sieve analyses of these samples indicated a clayey silt or silt classification, with porosities ranging from 0.36 to 0.44%. The geotechnical reports are provided in *Assembly E RFI Report* (EnSafe, 2000).

The upper 6 or 7 feet of the loess are typically dry. A moist to wet zone encountered from 10 to 16 feet bls in most SWMU 14/46 soil borings represents the uppermost water-bearing zone here at the site. Depth-to-groundwater measurements in SWMU 14/46 loess monitoring wells have ranged from 4.99 feet to 7.96 feet bls (014G01LS and 014G05LS). Loess groundwater migrates primarily downward, although locally, some water in the loess may discharge to nearby streams, drainage ditches, and other surface-water bodies. The average loess horizontal groundwater velocity calculated from the direct-push technology (DPT) investigation results at SWMU 14/46 was 3.44×10^{-5} cm/sec, or 0.09 feet per day.

The fluvial deposits underlie the loess at SWMU 14/46. The upper portion of the fluvial deposits consists of a silty, clayey, fine- to medium-grained sand; at some locations, it also contained scattered quartz and chert gravel up to three quarters of an inch in diameter. In general, the grain size of sand coarsened with depth. The percentage of gravel and its maximum diameter also generally increased with depth. In most soil borings, the base of the fluvial deposits consisted of a sand-and-gravel mixture, with gravel up to 4 inches in diameter. The percentage of gravel within the sand matrix varied from approximately 10% to 75%, depending on the boring location. The fluvial deposits range from 12 to 20 feet thick at SWMU 14/46 to 33 to 47 feet thick at southside background well locations.

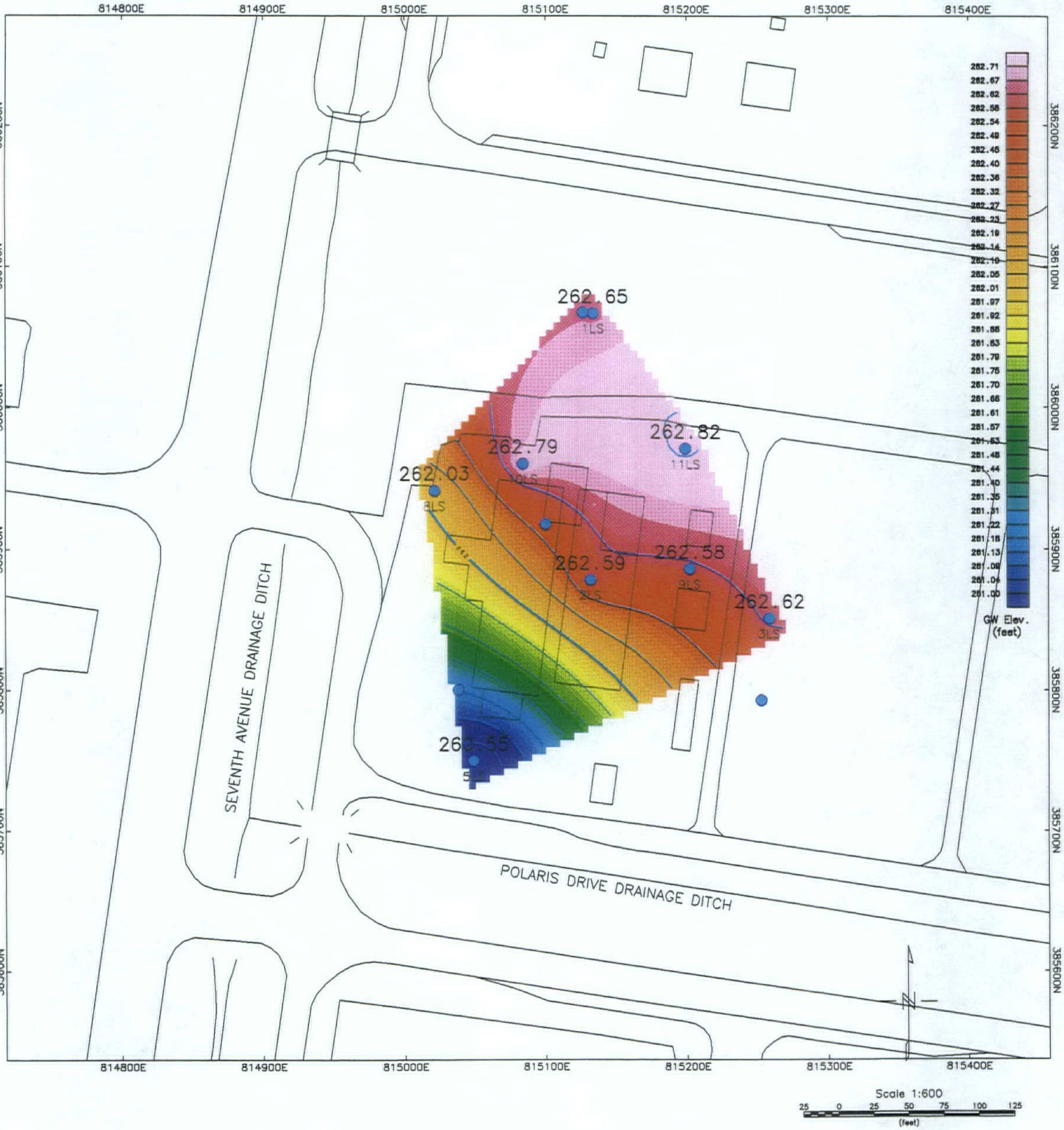
As shown in Figure 2-3, groundwater elevations in SWMU 14/46 loess monitoring wells measured in March 2003 were used to generate a computer-contoured potentiometric-surface map for the site. The figure indicates a horizontal component of groundwater beneath SWMU 14/46 that generally is to the southwest, toward the Seventh Avenue and Polaris Drive drainage ditches.

2.3 Aquifer Characterization

The permeability coefficient of the sample collected from the fluvial deposits was found to be 4.0×10^{-7} cm/sec (location 014S01LF). Sieve analyses and porosity testing classified the sample from location 014S01LF as a silty clay containing sand and small gravel with a porosity of 32%. The approximate horizontal gradient of groundwater in the fluvial deposits beneath SWMU 14/46 is 0.005 feet/foot. Based on these data, the horizontal groundwater velocity in the fluvial deposits is 3.98×10^{-5} cm/sec, or 0.11 feet per day. A horizontal groundwater velocity for SWMU 14/46 fluvial deposits also was calculated from specific capacity testing of monitoring well 014G07LF at 0.14 feet per day.

2.4 RFI Sampling Results

During November 1995, a preliminary DPT screening investigation was conducted at SWMU 14/46 as part of the RFI characterization. Based on the anticipated site contaminants from paint-related activities, volatile organic compounds (VOCs) were chosen as the indicator parameter. PCE and TCE were detected at concentrations exceeding maximum contaminant levels (MCLs) in groundwater from the loess and fluvial deposits at the DPT locations. The results of the DPT investigation were then used to define the nature and extent of contamination during the subsequent RFI.



PLOT SUMMARY
- Groundwater levels obtained from loess monitoring wells, March 2003
- Light contours every 0.2 foot, heavy contours every foot
- Labeled wells are loess wells; unlabeled are fluvial deposits wells

- Drawing file: 0146GEO.DXF
- Plotted via Geosoft 09-22-04
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Figure 2-3

March 2003 Loess Potentiometric Map

SWMU 14 Interim Measures Work Plan
NSA Mid-South, Millington, TN

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2.4.1 Soil Sampling Results

During the RFI, soil samples were collected from the SWMU 14/46 area. Analytical results indicated a release of chlorinated solvents and petroleum-related compounds. Although VOCs were detected, only acetone exceeded its screening value in one surface soil sample. Total petroleum hydrocarbons (TPH)-Diesel Range Organics (DRO) and TPH-Gasoline Range Organics (GRO) also were detected in soil samples; however, none exceeded the TDEC cleanup level of 500,000 microgram per kilogram (μg/kg) for non-drinking water aquifers. Because minimal contamination was found, the RFI recommended no further action for soil at SWMU 14/46.

2.4.2 Groundwater Sampling Results

Based on the DPT investigation results, five loess and four fluvial deposits monitoring wells were installed in the SWMU 14/46 area. Results from groundwater sampling show *cis*-1,2-dichloroethene (DCE), PCE, and TCE exceeding their respective MCL in loess groundwater. In addition, TPH exceeded TDEC's most stringent action levels in loess and fluvial deposits groundwater samples. As recommended by the RFI, supplemental groundwater sampling was conducted in all nine groundwater monitoring wells during October 2000. Because loess groundwater likely will never be used as a potable water source at NSA Mid-South because of its low yield and poor aesthetic quality, detected concentrations of TPH in samples collected from loess wells are compared with TDEC's groundwater cleanup level of 1,000 micrograms per liter (μg/L) for non-drinking water aquifers. TPH concentrations found in fluvial deposits monitoring wells are compared to the TDEC's most stringent groundwater cleanup level of 100 μg/L for drinking water aquifers. TDEC and USEPA concurred with this recommendation in letters dated March 16, 2001, and June 27, 2001, respectively.

Results of the supplemental sampling indicate that PCE and TCE concentrations remain greater than their respective MCLs in loess monitoring well 014G02LS. TPH concentrations were found to be less than the state groundwater cleanup standard of 1,000 μg/L for non-drinking water aquifers in all loess monitoring wells. The CMS work plan concluded that remediation of PCE and TCE in loess groundwater should be evaluated in a streamlined CMS, which should evaluate natural attenuation. Because TPH did not exceed the TDEC action level, the work plan recommended no further investigation of TPH on loess groundwater (EnSafe, 2001).

No VOCs were detected in concentrations greater than their respective MCLs in any fluvial deposits monitoring well. TPH concentrations were less than the state groundwater cleanup standard of 100 μg/L in all fluvial deposits monitoring wells. Based on these findings, the CMS work plan recommended no further investigation of fluvial deposits groundwater (EnSafe, 2001). The CMS work plan was approved by TDEC and USEPA in letters dated August 27, 2001, and June 4, 2001, respectively.

2.5 Treatability Study

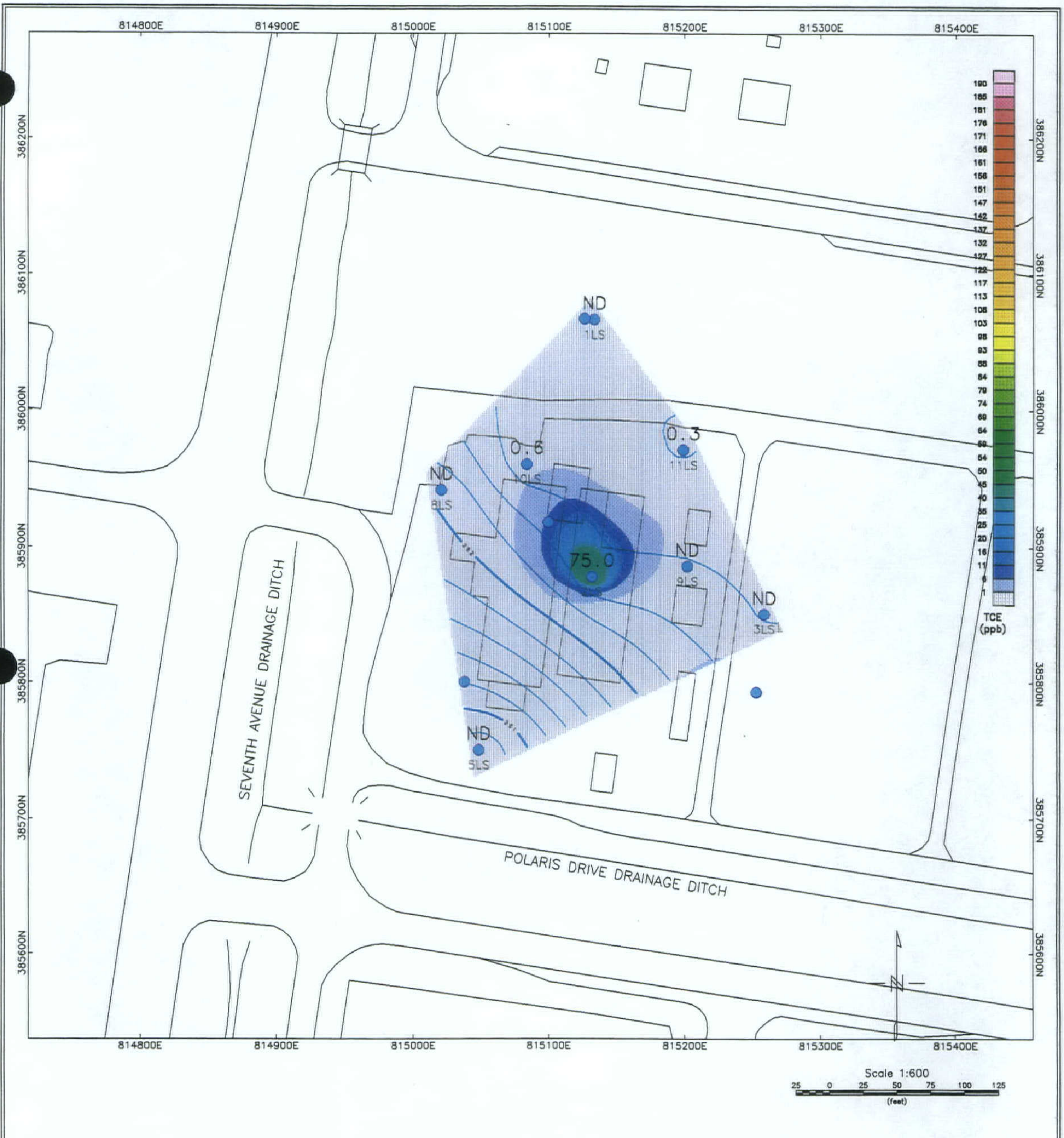
As discussed in the CMS work plan (*EnSafe, 2001*), MNA was identified as the alternative most likely to achieve the remedial goals for SWMU 14/46. An MNA Treatability Study work plan was then developed to monitor the area over time and to verify that natural attenuation is occurring at rates sufficient to attain site-specific remedial goal options (RGOs). Complete information on this program is provided in the *Monitored Natural Attenuation Treatability Study Work Plan — SWMU 14/46* (EnSafe, August 2001).

To further evaluate the extent of chlorinated solvents in loess groundwater, the monitoring program included the installation of three additional loess monitoring wells at locations north and northwest of 014G02LS. The monitoring program also implemented quarterly groundwater sampling of the three new wells and the other five existing loess wells at SWMU 14/46 for one year. The samples were analyzed for VOCs and geochemical parameters. Quarterly monitoring took place in May, August, and December 2002, and March 2003.

PCE and TCE exceeded their MCLs in each quarterly sample collected from well 014G02LS. No other detections of VOCs exceeded MCLs. Additional samples were collected for geochemical analysis during quarterly monitoring.

The CMS for SWMU 14/46 concluded that although some natural TCE bioattenuation (MNA) is occurring in the aquifer, groundwater would likely have to be amended with an organic compound (which it is now lacking) to sustain rapid reductive dechlorination, a process which can reduce TCE to harmless end products.

A graphical computer model was used to visually interpret the loess groundwater data and develop a conceptual model of the contamination at SWMU 14/46. The model-generated plume map showing TCE concentrations detected in NSA Mid-South SWMU 14/46 loess groundwater in March 2003 is presented in this report as Figure 2-4.



PLOT SUMMARY
- Sampling data obtained from loess monitoring wells only, March 2003
- Potentiometric data for March 2003 (contours)
- Labeled wells are loess wells; unlabeled are fluvial deposits wells

- Drawing file: 0146GEO.DXF
- Plotted via Geosoft 10-08-04

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Figure 2-4
March 2003 TCE
SWMU 14 Interim Measures Work Plan NSA Mid-South, Millington, TN
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3.0 ENHANCED IN SITU BIOREMEDIATION

Enhanced in situ bioremediation is the engineered manipulation or modification of groundwater geochemical and redox conditions to stimulate the biodegradation of dissolved-phase chlorinated solvents. Redox modification (reduction in most cases) is achieved by the addition of a nutrient (a synthetic or natural carbon compound that can be used as a source of energy) to the groundwater. The carbon is used by native groundwater microorganisms to consume any dissolved oxygen present and ensure an anaerobic environment, which is essential for TCE biodegradation. The carbon also provides a continual energy source for native microorganisms as they slowly acclimate to reducing conditions and begin using chlorinated solvents as electron acceptors. The process is termed reductive dechlorination, by which the chlorine atoms of PCE and TCE are replaced with hydrogen to transform these compounds into lesser chlorinated daughter products, such as 1,2-dichloroethylene (DCE) and vinyl chloride (VC). If properly engineered, the process could result in partial or complete reduction of TCE to harmless end-products.

3.1 Technology Description

To achieve reducing (anaerobic) conditions, the subsurface is augmented by engineering means to accelerate the biodegradation of organic contamination. To create an anaerobic zone, simple carbohydrates (e.g., fructose or acetate) and micro-nutrients are added to the groundwater. The carbohydrates provide a food source that stimulates microbial activity, manipulates groundwater redox conditions, and creates an anaerobic zone necessary for TCE and PCE degradation. TCE intercepted in the anaerobic zone breaks down fairly early to lesser chlorinated compounds such as 1,2-DCE or VC, which are subsequently degraded to innocuous end products either by continued reductive dechlorination, induced aerobic oxidation (described as follows), or by natural attenuation.

Unlike PCE and TCE, the daughter products 1,2-DCE and VC are more readily degraded in an aerobic environment. If a natural downgradient aerobic zone is not present, it can be created by injecting air into the aquifer using sparging wells connected to an aboveground blower. Carbon and nutrients can also be added to the air-sparging wells to enhance the aerobic degradation of 1,2-DCE and VC. The aerobic degradation of DCE and VC forms innocuous end products such as carbon dioxide (CO_2) and water.

3.2 Enhanced In Situ Bioremediation Pilot Study at NSA Mid-South

A pilot study to evaluate enhanced in situ bioremediation has been completed at another location within NSA Mid-South designated as Area of Concern (AOC) A. This pilot study evaluated the use of a type of enhanced in situ bioremediation known as Anaerobic-Aerobic (A-A) Sequential Bioremediation to address TCE contamination in fluvial deposits groundwater on the NSA Mid-South Northside.

3.2.1 A-A Sequential Bioremediation Pilot Study

Also known as "two-zone interception treatment", A-A sequential bioremediation relies on groundwater flow through sequential anaerobic and aerobic zones to treat the chlorinated solvent contamination. An A-A sequential bioremediation pilot study was performed to evaluate the feasibility of using enhanced in situ bioremediation to remediate the contaminated fluvial deposits groundwater at AOC A, specifically the area of higher chlorinated solvent contamination in near monitoring well 007G04LF (southeast side of Building N-126). The following briefly describes the A-A pilot study and its findings.

The pilot study was performed in the area around monitoring wells 04LF and 04UF where the highest TCE concentration of 4,400 μg/L was measured in March 1999. This pilot system consisted of one extraction well (57LF), two injection wells (60LF and 61LF), and four monitoring wells (58LF, 59LF, 62LF, and 63LF). The pilot study area is shown in Figure 3-1.

During the pilot study, groundwater was pumped from the extraction well to a 500-gallon holding tank and then reinjected into the two injecton wells. Prior to reinjection, the pumped water was periodically augmented or dosed with designed quantities of nutrients (a synthetic carbon and nitrogen source). Groundwater wells in the test area were monitored for field geochemical parameters such as pH, dissolved oxygen (DO), ORP, and CO_2 to optimize system operation and

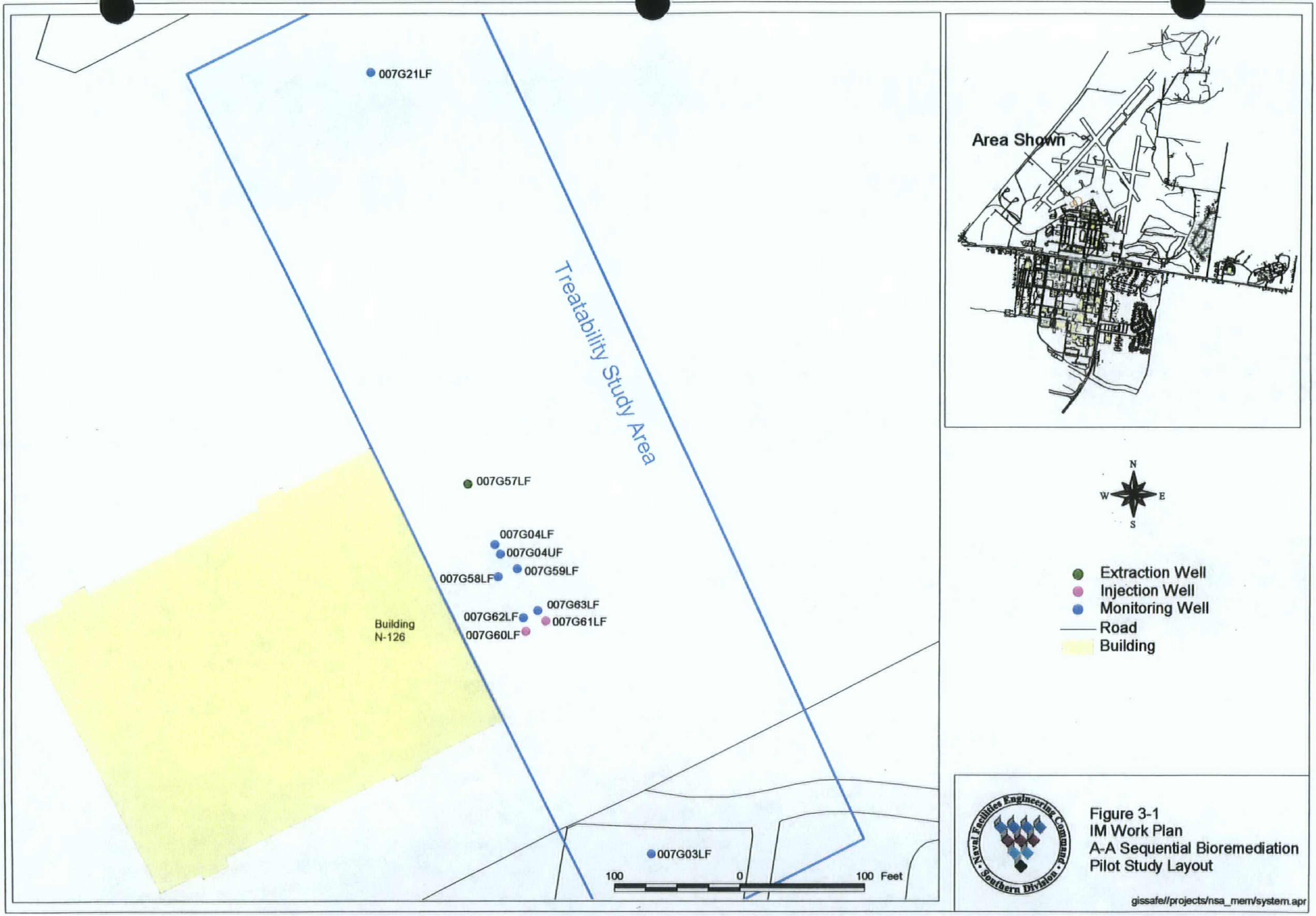

Figure 3-1
IM Work Plan
A-A Sequential Bioremediation
Pilot Study Layout

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assess the response of the treatability study during the evaluation process. Details of this pilot study are presented in the *A-A Sequential Bioremediation Report* (EnSafe, 2002).

A-A Pilot Study Results

The A-A pilot study system operated from March 14, 2000, to December 15, 2000. The results collected during the nine-month treatability study showed that reductive dechlorination of PCE and TCE is feasible via enhanced bioremediation. The most significant observation was the two-order-of-magnitude increase in *cis*-1,2-DCE concentrations in the study area monitoring wells. By March 2001, approximately 50% of the baseline contaminant mass (TCE) had been reduced. The attainment of reducing conditions in the fluvial deposits during the study was confirmed by negative ORP measurements, low DO concentrations, and elevated hydrogen concentrations during field geochemical sampling.

Post-Shutdown Results

Following the nine-month active study, the system was monitored under passive conditions to study continued degradation in a sustained anaerobic environment. Field samples were routinely collected from pilot study wells to monitor the aquifer's geochemistry. Analytical samples were collected in March and July 2001, as well as February and September 2002, to continue monitoring chlorinated VOC concentrations in the area following system shutdown. Stopping the recirculation system and returning the aquifer to natural hydraulic conditions resulted in a relatively stagnant environment, particularly near the injection wells (007G60LF and 007G61LF) and first row of monitoring wells (007G62LF and 007G63LF). This stagnancy, coupled with ample[1] residual organic carbon in the groundwater, resulted in much stronger anaerobic conditions than expected, resulting in *cis*-1,2-DCE degradation to VC.

[1] Compared with pre-shutdown samples, TOC concentrations in samples from the injection wells and 007G62LF and 007G63LF monitoring wells were one to two orders of magnitude higher after the system was shut down.

Consistent with the analytical results, ORP measurements collected from the injection wells have ranged from -150 to -200 milliVolts since system shutdown, which is likely low enough for *cis*-1,2-DCE and VC degradation. This phase showed that DCE continued to further degrade to measurable amounts of VC in the aquifer. Data collected in July 2001 and February 2002 indicated that the VC that was formed was decreasing near the injection wells. Specialized microbial analysis from groundwater samples indicated the presence of bacteria *(dehalococcoides ethenogenes)* that have the ability to fully dechlorinate TCE. In general, the addition of nutrients stimulated the growth of native microorganisms as indicated by biomass counts and comparing populations between upgradient and pilot area monitoring wells.

Figure 3-2 illustrates spatial contaminant variations throughout the pilot-study area before and after system implementation.

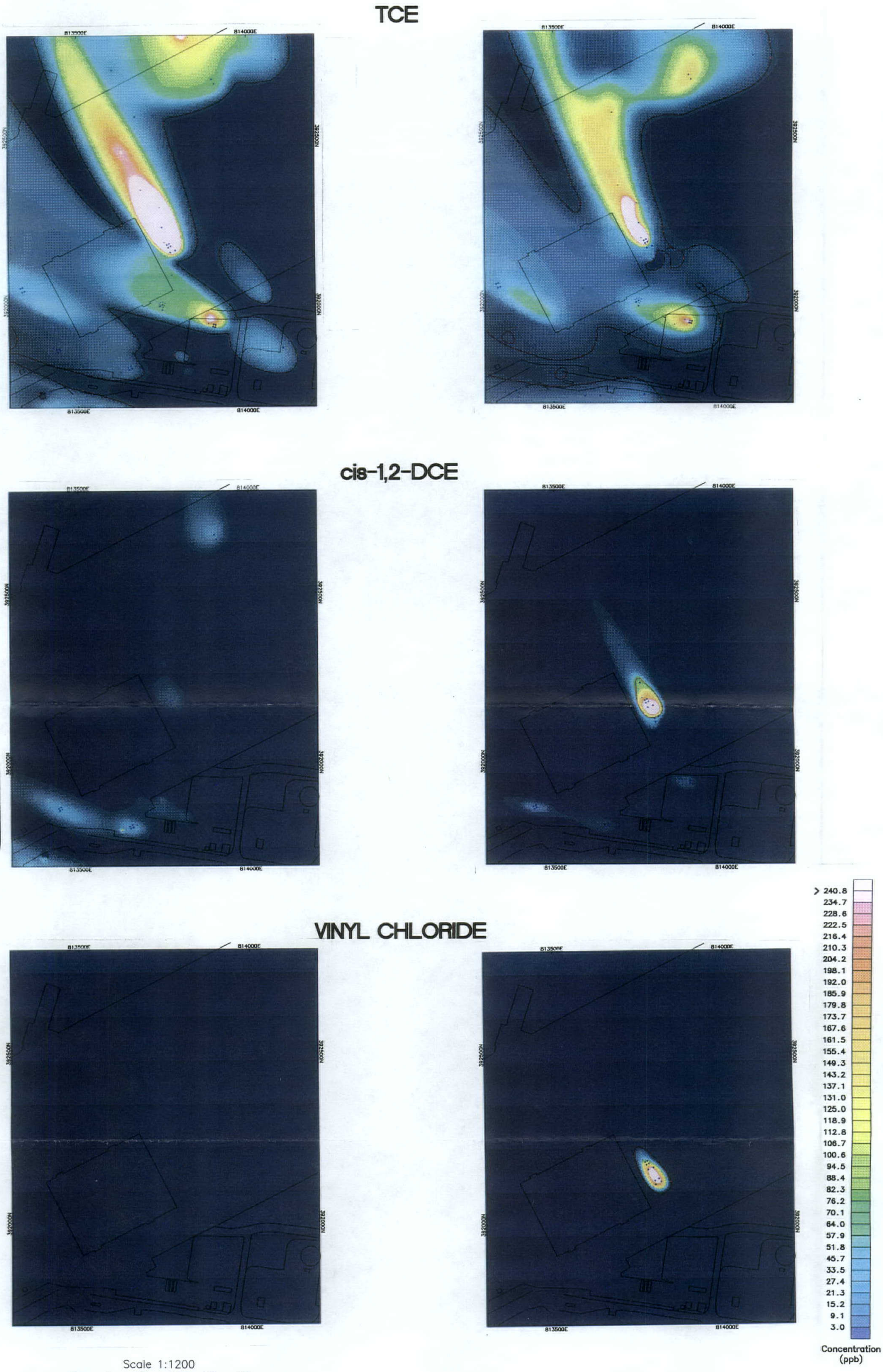
3.3 Summary

Based on the results of the AOC A pilot study, it appears that a soluble organic substrate would be more effective for enhancing aquifer geochemistry to promote relatively rapid in situ biodegradation at NSA Mid-South. In summary, the A-A sequential bioremediation pilot study has shown that passive injection of carbohydrates and micro-nutrients can adequately stimulate TCE biodegradation in the aquifer. Post-shutdown results indicate that sufficiently anaerobic conditions can be generated to promote PCE/TCE dechlorination. The A-A system also indicated that daughter product concentrations are slowly decreasing over time. Finally, microbial analysis indicated that indigenous microbes capable of degrading *cis*-1,2-DCE and VC are present in the aquifer.

Because post-shutdown monitoring was performed essentially under natural hydraulic conditions, the findings indicated that a full-scale, passive system, whereby the groundwater was augmented to create and sustain a reducing environment, would be a feasible alternative. Because of the

BEFORE A-A
MAX 1995–1999

AFTER A-A
JUL 2002



Scale 1:1200

50 0 50 100 150 200 (feet)

PLOT SUMMARY
- Contaminant conceptual model
- Red contours are the MCL boundaries

- Drawing file, base map in color plots: CMSMAP.DXF
- Color plots generated 11-24-03 via Geosoft, inserted to CAD border
- N:\WP51\USERS\LHUGHES\MEMPHIS\GEOCHEM\PLUMES\ISM03\SMALL\16.P01

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SWMU 14/46
NSA MID-SOUTH
MILLINGTON, TENNESSEE

FIGURE 3-2
TCE, cis-1,2-DCE, AND VC CONCENTRATIONS IN A-A PILOT STUDY AREA BEFORE AND AFTER IMPLEMENTATION

DWG DATE: 10/07/04 | NAME: 0146001W080

inherent aerobic nature of the aquifer (and the geochemical sampling results which showed an aerobic aquifer in hydraulic downgradient locations), it is likely that natural attenuation will further degrade any cis-1,2-DCE and VC that is created and not destroyed via the passive enhanced system.

A similar approach of this pilot study could be effective to treat TCE-contaminated groundwater at SWMU 14/46. Because the loess comprises less permeable soil compared to fluvial, the time available for reductive dechlorination should be greater. In other words, the contaminants and daughter product biodegradation rates are likely to be faster than their migration rates in groundwater. Furthermore, the concentration of PCE/TCE is an order of magnitude lower compared to those detected at AOC A. Therefore, the CMS report concluded that enhanced bioremediation coupled with MNA would be an effective remedial approach at SWMU 14/46 (EnSafe, 2003). It recommended the implementation of a passive system to remediate the existing TCE plume. The following sections describe the design, implementation, and monitoring of a passive enhanced bioremediation system.

4.0 ENHANCED IN SITU BIOREMEDIATION FULL-SCALE DESIGN

The enhanced in situ bioremediation system will consist of a series of injection wells located in the plume of concern outlined in Section 2. The most recent plume map shown in Figure 2-4, which is based on groundwater sampling results from the March 2003 event, was used to locate injection wells. In addition, geochemical results were also used to space the injection wells. The major elements of the initial system design are discussed in the following subsequent sections. Recommendations to enhance the system may be made based on the results from effectiveness monitoring.

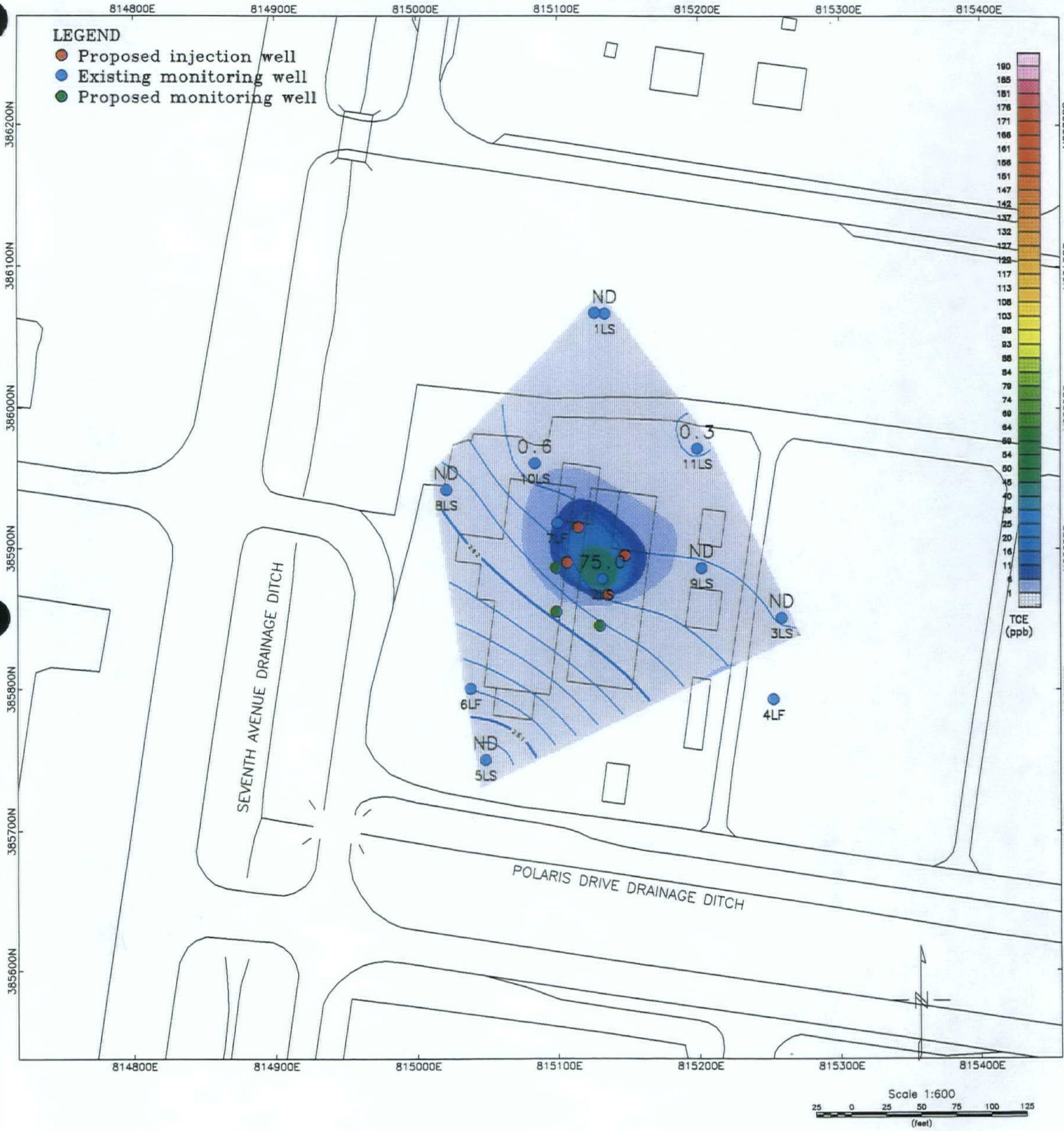
4.1 Selection, Location, and Design of Substrate Injection Wells

The injection wells have been selected based on several criteria. Figure 2-4, the current TCE plume configuration, shows the highest TCE-contaminated area is located in the vicinity of 014G02LS.

4.1.1 Injection Well Location Design

A total of four injection wells are proposed to remediate this plume. The locations of these wells were selected so that groundwater around 014G02LS would be treated passively at the inception of the remedy. The four wells are located along two transects with two wells each. Within each transect, wells are spaced approximately 25 feet apart. One transect is located immediately upgradient and the other immediately downgradient of 014G02LS. Any groundwater flowing through the area of 014G02LS would flow past these injection wells. Injection well locations are presented in Figure 4-1.

It is expected that the entire plume should be amended with the added carbon substrate within nine months. Based on the results of the A-A sequential bioremediation pilot study, reductive dechlorination occurs within 2 to 3 months after substrate injection has been initiated. Therefore, nine months should be sufficient to reduce the bulk of the chlorinated solvent mass in the aquifer. Quarterly monitoring will be used to decide if more transects are required. The objective of the injection well locations is to surround the contaminated location 014G02LS and ensure amendment of groundwater in the aquifer in its vicinity.



PLOT SUMMARY
- Sampling data obtained from loess monitoring wells, March 2003
- Potentiometric data for March 2003 (contours)

- Drawing file: 0146GEO.DXF
- Plotted via Geosoft 09-24-04
n:\wp51\users\lhughes\memphis\north-gw\swmu14\13.P01

Figure 4-1

Injection Well Location Diagram

SWMU 14 Interim Measures Work Plan
NSA Mid-South, Millington, TN

EnSafe Inc.

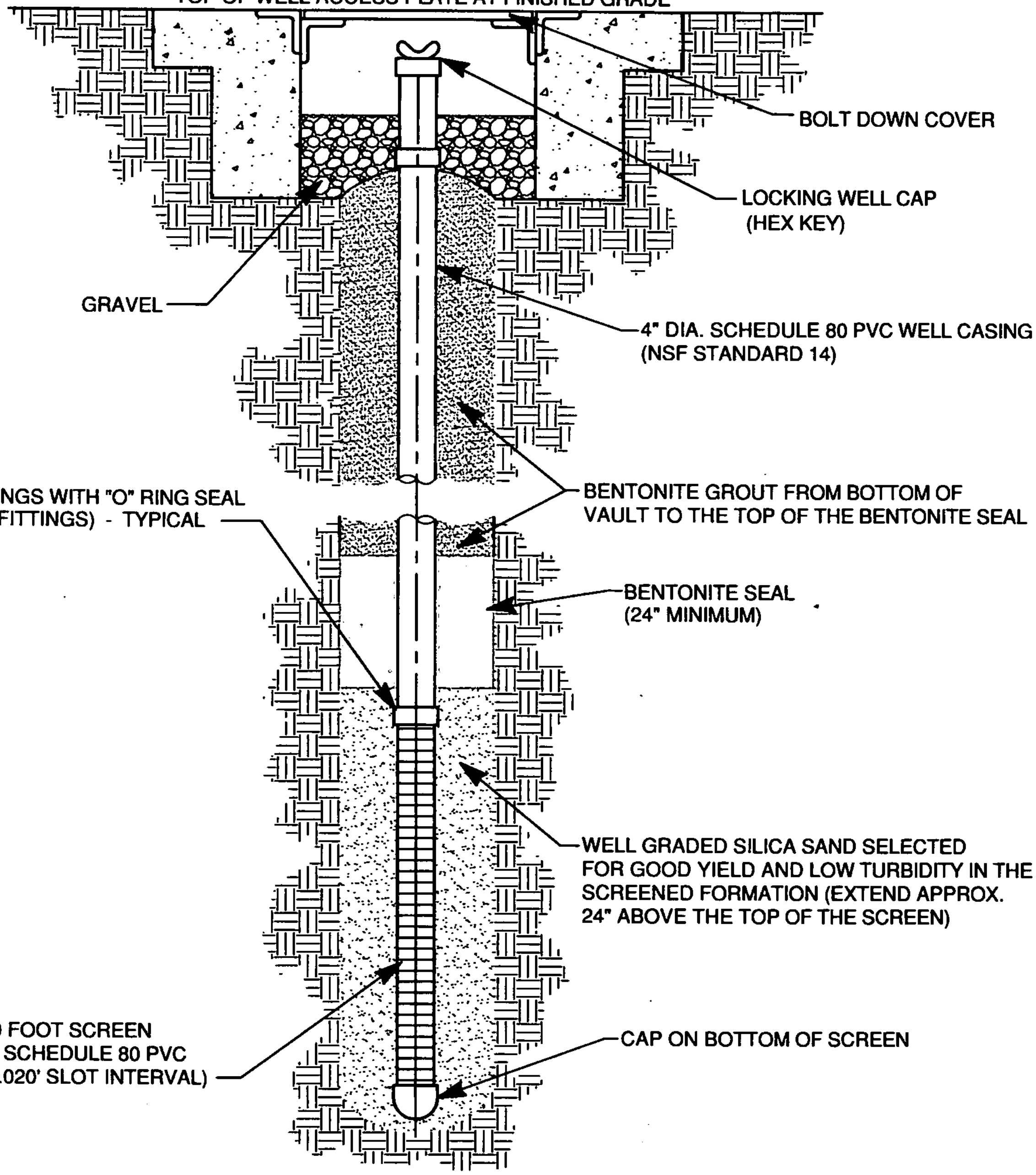
4.1.2 Well Design

Two types of wells will be installed during remediation as shown in Figure 4-1. The first is a series of substrate injection wells. The second is a set of new remediation effectiveness monitoring wells intended to supplement the existing monitoring well network to provide sufficient data collection points to evaluate remediation effectiveness. As described earlier, the substrate injection wells will be used to periodically inject designed quantities of nutrients (carbon and nitrogen-based compounds) to stimulate reductive dechlorination. The new effectiveness monitoring wells and select existing monitoring wells will be sampled periodically for field and laboratory chemical and geochemical analysis. Sampling results from the remediation effectiveness monitoring wells will be used to gauge the effectiveness of the system, recommend and implement changes in the substrate injection strategy as needed, and examine the need for more injection wells.

Figure 4-2 shows the details of the substrate injection well. These wells will be installed to a total depth that corresponds to the base of the loess. The screen length to attain this objective is approximately 15 to 25 feet bgs across the thickness of the loess. Injection wells will be constructed of 4-inch-diameter, flush-threaded, Schedule 80 polyvinyl chloride (PVC) riser pipe attached to a 0.02-inch slot size screen constructed of similar material. All wells will be completed as flush-mount installations protected by a steel cover as shown in Figure 4-2.

Three new monitoring wells will be installed for sampling purposes. As shown in Figure 4-1, the monitoring wells will be installed downgradient of the injection well area and used to gauge remedial effectiveness. The new monitoring wells have similar specifications as the substrate injection wells, except the well diameter will be 2 inches instead of 4 inches and Schedule 40 PVC will be used.

All boreholes for the well installations will be drilled using the hollow-stem augers drilling method consistent with the general procedures described in Section 6.3.3 of the USEPA Region 4 Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM). The only soil sampling that will be performed during the well installations will be for lithological characterization and logging. The lithological data will be used to determine well depths



TYPICAL ILLUSTRATION OF INJECTION WELL CONSTRUCTION IN CONFINED AQUIFER

NOT TO SCALE

NAVFAC Naval Facilities Engineering Command SOUTHERN DIVISION	INTERIM MEASURES SWMU 14/46 NSA MID-SOUTH MILLINGTON, TENNESSEE	FIGURE 4-2 TYPICAL INJECTION WELL
	Date: 10/12/04	DWG Name: 0146001W081

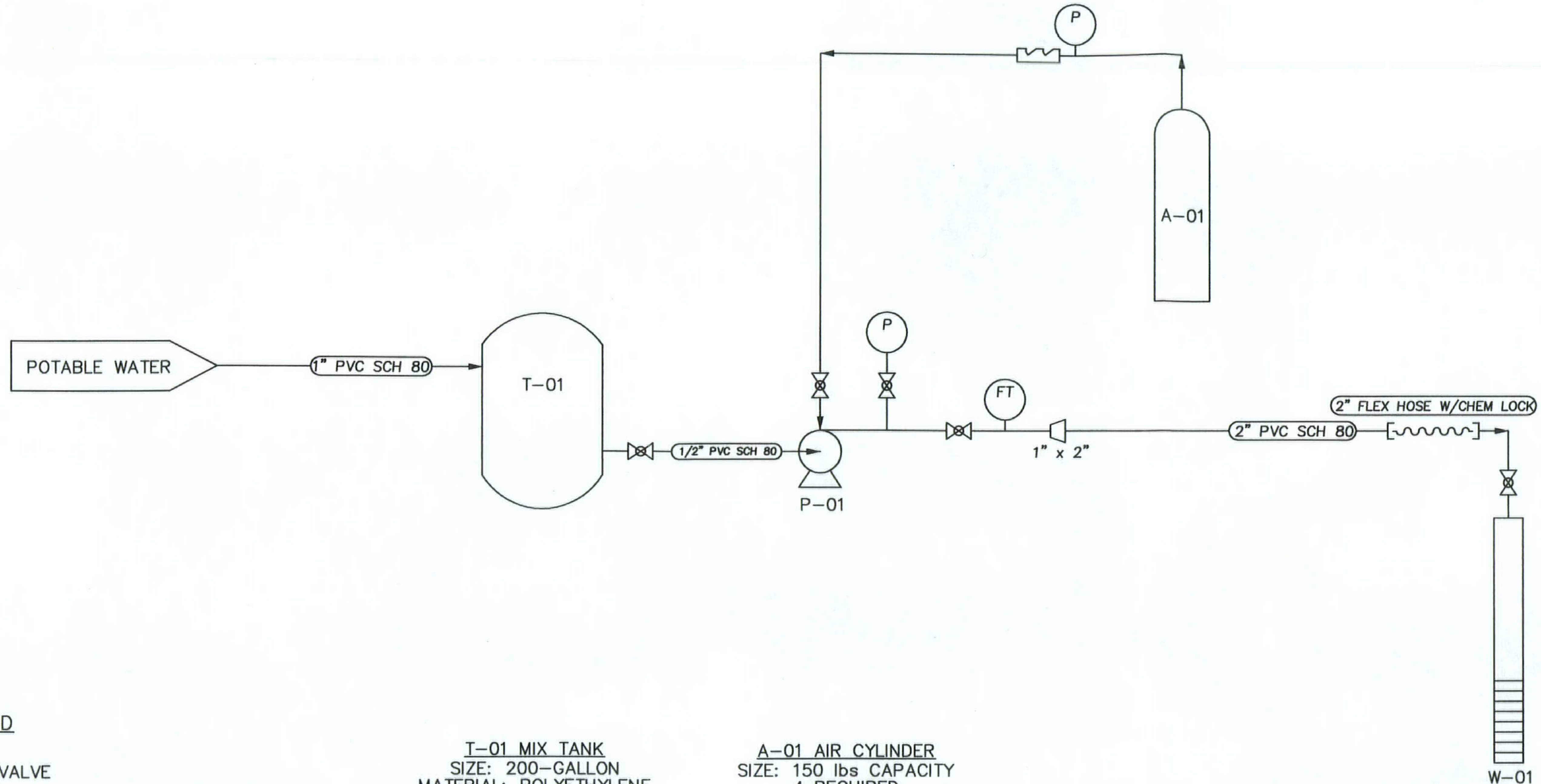
and material amounts for the installation. The monitoring wells will be installed in accordance with the well construction procedures outlined in Section 4.5.3 of the *Comprehensive RFI Work Plan* (EnSafe, 1993) prepared for NSA Mid-South and Section 6.4 of the EISOPQAM. All investigation derived waste generated during the installation and subsequent development of the wells will be managed in accordance with Section 4.12 of the *Comprehensive RFI Work Plan.*

4.2 Substrate Feed Design

Substrate injection (injection of the selected soluble carbon compound and nutrients) will be performed using a mechanical feed system. A setup and flow diagram of the mechanical feed system is shown in Figure 4-3. The mechanical feed system will be mounted on a flat bed trailer that can be attached to a standard four-wheel truck. A 200-gallon polyethylene tank will be used for mixing. A pneumatically controlled pump will be used for injecting the chemical-laden water from the tank to the injection wells. A compressed air tank will be the air source supply as shown in Figure 4-3. The pump has the capacity to inject up to 15 gpm at a maximum pressure of 125 pounds per square inch (psi). Flow and pressure regulators are also shown in Figure 4-3 and will be used to control chemical feed into the system.

4.3 Substrate Addition Strategy

The A-A pilot study showed that sodium acetate successfully created the reducing conditions necessary for chlorinated solvent biodegradation. In addition, designed quantities of ammonium phosphate were used as a micronutrient for microorganisms. These biostimulants were mixed in powder form and added to the injection wells in a liquid stream. Full-scale remediation at SWMU 14/46 will follow the augmentation/stimulation strategy observed during the pilot study.



LEGEND

- PVC BALL VALVE
- REDUCER
- PRESSURE GAUGE
- FLOW TOTALIZER
- PRESSURE REGULATOR W/OIL LUBE & FILTER
- [ ] — CHEM LOCK
- FLEX HOSE

T-01 MIX TANK
SIZE: 200-GALLON
MATERIAL: POLYETHYLENE

A-01 AIR CYLINDER
SIZE: 150 lbs CAPACITY
4 REQUIRED

P-01 DIAPHRAGM PUMP
SIZE: 1/2" PNEUMATIC
(EXISTING)

W-01 INJECTION WELL
SIZE: 4" DIAMETER

NOTE: ACETATE FEED SYSTEM WILL BE MOUNTED ON A FLAT BED TRAILER.

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MILLINGTON, TENNESSEE

FIGURE 4-3
ACETATE FEED SYSTEM

DWG DATE: 10/11/04 | NAME: 0146001B026

One hundred gallons of dissolved-sodium acetate solution will be added to each injection well monthly. Every one hundred gallons of sodium acetate will contain 50 pounds of dissolved sodium acetate. In addition, one part by weight of ammonium phosphate will be added for every 100 parts by weight of sodium acetate. Both of these additives are completely soluble in water at the specified quantities. It is expected that the quantities added will sufficiently convert and maintain the plumes in an anaerobic zone and provide the carbon source necessary to reduce TCE.

Mixing and injection is expected to be performed in a single day. A written log of mixing and injection will be established. Any changes to the quantities added will be made if needed based on the progress of remediation and groundwater chemical and geochemical data.

4.4 Tracer Study

A tracer study will be performed at the site to confirm groundwater velocity and dispersive characteristics that have been used to locate and space substrate injection wells. Additional injection wells may be proposed, if needed, based on results of the tracer study. A tracer is a substance in groundwater that carries information about the groundwater system. The tracer study will involve the injection of potable water amended with bromide into a single injection well. After injection, area monitoring wells will be monitored to determine the study progress.

Bromide has been chosen for the tracer study to be performed at SWMU 14. It is water soluble, highly detectable and inexpensive. As part of this study, approximately 50 lbs of bromide will be injected into a single injection well immediately upgradient of 014G02LS. Bromide does not have any toxicity issues at the proposed levels of injection and expected final concentrations.

The fifty pounds of bromide will be mixed with approximately 200 gallons of water. The tracer injection will occur over one day. Once the solution is properly mixed, the tracer will be injected. Flushing with three borehole volumes of potable water will be conducted directly after the tracer injection in order to mobilize the mixture.

Post-injection sampling will be conducted. The monitoring wells will be sampled by using micro-purge/low flow sampling techniques. Samples will be collected from monitoring wells 014G02LS and 014G05LS, the three additional injection wells, and the three new monitoring wells. Groundwater will be collected and contained in proper glass vials. All samples for the tracer study will be sent to Environmental Testing Consultants, Memphis, Tennessee to be analyzed for bromide. Sampling will continue for approximately 3 to 6 months or until sufficient data is gathered.

5.0 PERMIT REQUIREMENTS

The permits required to perform the interim measures activities are summarized in Table 5-1.

Table 5-1
Permit Summary

Task	Permit Required	Agency/Contact
Monitoring Well Installation	Well construction permits	Memphis and Shelby County Health Department (MSCHD)/Greg Parker
Substrate Injection[2]	Injection well permit/variance	MSCHD/Greg Parker
	Class V Injection Well Authorization	TDEC Division of Water Supply/Bruce Craig
	Dye Trace Registration	TDEC Division of Water Supply/Bruce Craig

[2] Per Section 13 of the Memphis/Shelby County Water Well Regulations, no injection wells of any type shall be allowed in Memphis and Shelby County for the injection of surface or groundwater, or chemically or thermally altered water, or any other fluids into the underground formations. Injection wells for the purpose of improving groundwater quality, however, may be considered under Section 14.02.

6.0 EFFECTIVENESS MONITORING

Groundwater monitoring would be required to assess enhanced in situ reduction. Onsite effectiveness monitoring would include analysis of chemical and geochemical parameters to gauge remediation effectiveness. Some parameters will be analyzed in the field while others will be submitted for laboratory analysis. Table 6-1 lists effectiveness monitoring parameters and the corresponding method that will be used to analyze them. Ideally, wells would be monitored in the targeted area, upgradient and downgradient of the application; background wells would also be sampled. Monitoring well locations are shown in Figure 4-1. The following wells will be monitored as part of the effectiveness monitoring program: 014G01LS, 014G02LS, 014G03LS, 014G05LS, 014G10LS, and the three new proposed monitoring wells. In addition, 014G06LF and 014G07LF will be sampled annually for VOCs.

Groundwater samples will be collected before the initial injections to establish baseline chemical and geochemical data in the targeted area. After the baseline event, samples will be collected quarterly. All sampling will be performed in accordance with the Quality Assurance Plan and the Sampling and Analysis Program developed as part of the RFI for this site.

Sampling results will be used to estimate TCE mass reduction and approximate VOC degradation rates. Geochemical parameters, such as DO and ORP, will be used in the operation and optimization of the system and to assess the geochemical response of the aquifer. Reductant redosing rates would depend on the plume management strategy, site-specific biodegredation performance, remedial goal options, and other technical or regulatory considerations. Water levels will be measured prior to and during bioremediation to assess the hydrogeologic effects of injection into the groundwater. Water levels will be measured in monitoring wells within a 100-foot radius of the target area.

Table 6-1
Enhanced In Situ Bioremediation Quarterly Sampling Analytes/Parameters

Analyte	Method
Laboratory	
VOCs	SW8260B
Hydrogen	AM20GAX
methane, ethane, and ethene	8015MOD
Nitrate	353.3
TOC	SW9060
major cations	SW6010
Field	
ferrous iron	portable colorimeter
sulfate and sulfide	portable colorimeter
DO	YSI 55 DO meter calibrated prior to use per manufacturer's instructions
ORP	Orion 250A ORP meter or equivalent calibrated prior to use per manufacturer's instructions
pH	pH meter
temperature	temperature probe
Alkalinity	portable colorimeter
Chlorides	portable colorimeter
phosphorus and ammonia-nitrogen	portable colorimeter

7.0 SCHEDULE AND REPORTING

7.1 Schedule

Following submission and approval of the IM work plan, the system will be installed. The IM implementation schedule is shown in Figure 7-1. The schedule is subject to minor variations depending on equipment availability, unexpected weather conditions, unforeseen site conditions, and degradation progress during operations.

7.2 Reporting

Post-injection progress reports will be prepared semi-annually. Each report will include the following:

- Summarization of field activities and field/laboratory data
- Evaluation of the aquifer's geochemical condition: DO, ORP, redox zones (redox delineation), etc.
- Evaluation of microbial activity
  - Acclimation of reductive dechlorination
  - Biomass Counts
  - Microbial markers/structure
- Preliminary estimation of degradation rate
- Recommendations for system modifications

TASK	DURATION	PROJECTED START	PROJECTED FINISH	ACTIVITY
0003	30	09/01/04	10/13/04	Prepare/Submit IM Work Plan
0004	8	10/14/04	10/25/04	EPA/TDEC Review
0005	11	10/26/04	11/09/04	Revise/Submit IM Work Plan
0006	10	11/10/04	11/23/04	IM Well Installation
0007	10	11/10/04	11/23/04	EPA/TDEC Review/Approval
0008	5	12/14/04	12/20/04	Injection Event 1
0009	5	01/18/05	01/24/05	Injection Event 2
0010	5	02/22/05	02/28/05	Injection Event 3
0011	5	03/29/05	04/04/05	Injection Event 4
0012	5	05/03/05	05/09/05	Injection Event 5
0013	5	06/08/05	06/14/05	Injection Event 6
0014	5	07/14/05	07/20/05	Injection Event 7
0015	5	08/17/05	08/23/05	Injection Event 8
0016	5	09/22/05	09/28/05	Injection Event 9
0020	10	03/21/05	04/01/05	Post Injection Quarterly Monitoring Event 1
0021	10	07/05/05	07/18/05	Post Injection Quarterly Monitoring Event 2
0022	10	10/18/05	10/31/05	Post Injection Quarterly Monitoring Event 3
0024	30	08/17/05	09/28/05	Prepare and Submit Progress Report
0025	30	11/01/05	12/13/05	Prepare and Submit Progress Report

2004: SEP OCT NOV DEC — 2005: JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC — 2006: JAN FEB MAR APR MAY JUN

Start date	09/01/04
Finish date	12/13/05
Project name	EN05
Run date	10/07/04
Page number	1A

Early bar
Progress bar
Critical bar
Summary bar
Progress point
Critical point
Summary point
Start milestone point
Finish milestone point

NSA MID-SOUTH IM IMPLEMENTATION SCHEDULE

SWMU 14/46

NAVFAC

Figure 7-1

SWMU 14/46 IM IMPLEMENTATION
NAVAL SUPPORT ACTIVITY MID-SOUTH
MILLINGTON TN

8.0 REFERENCES

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9.0 SIGNATORY REQUIREMENTS

State of Tennessee Rule 1200-1-11.07(2)(a)8 states: All reports required by permits and other information requested by the Commissioner shall be signed by a person described in part 7 of this paragraph or by a duly authorized representative of that person. The certification reads as follows:

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Name
NSA Mid-South
Millington, Tennessee

Date